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16.	<p>Abstract: Total alkalinity and dissolved inorganic carbon are important parameters to understand the influence of anthropogenic carbon dioxide in oceans. Several basin scale empirical relations exist between total alkalinity and dissolved inorganic carbon with surface temperature, salinity and chlorophyll which can be exploited to understand large scale seasonal variability in ocean. We have used such established the empirical relations together with assimilated salinity and temperature a 1/4 degree regular grid to derive the global surface total alkalinity and dissolved inorganic carbon for research and development purpose.</p> <p>Key Words: Global; Salinity; Temperature; Alkalinity; dissolved inorganic carbon</p>			

Technical Report
On
Global Satellite Derived Surface Total Alkalinity and Dissolved
Inorganic Carbon for Biogeochemical Studies
Research and Development Product
Evaluation Version 1
2017

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Abstract

Total alkalinity (TA) and dissolved inorganic carbon (DIC) are important biogeochemical parameters which in tandem, can be used to understand the oceanic carbon dioxide system making it relevant in terms of climate change. Sea water total alkalinity is commonly defined as the excess base in the sea water and has gained importance due events such as ocean acidification. Seawater TA acts as a buffer for any change in the ocean pH and controlled by species composition of river which is determined by weathering. On the other hand dissolved compounds that make up the carbonate system in water are aqueous carbon dioxide (aqCO₂), bicarbonate (HCO₃⁻) and carbonate ion (CO₃²⁻). Measurements of any two of the seawater carbonate system variables (i.e., dissolved inorganic carbon, alkalinity, pH or partial pressure of carbon dioxide) in combinations with observations of temperature, salinity, silicate and phosphate concentrations are adequate to determine the complex CO₂ system. The measurement of alkalinity is particularly useful because of its conservative nature with respect to water mixing. Change in alkalinity is also independent of temperature, pressure unlike pCO₂, pH and concentrations of individual chemical species. Multiple studies have shown strong relationships between sea surface temperature, salinity and chlorophyll with TA and DIC suggesting the same can be exploited for observing basin scale changes. These relationships have been effectively used to estimate the surface pCO₂ fluxes in Atlantic, Pacific Ocean and Indian Ocean. Most of these methods are empirical in nature and region specific which exploit the relationships between chlorophyll, salinity, temperature with total alkalinity and dissolved inorganic carbon. Although all method has its own limitation satellite based estimates can give us synoptic view of basin scale changes if studied in regular interval. Satellite data together with insitu measurements may provide additional advantage in understanding oceanic process. For this purpose we have used the established TA and DIC empirical relations together with assimilated salinity and temperature from Copernicus Marine environment monitoring service for providing Global T, S, H, U, V Armo-3D L4 Analysis: Combined products from satellite observations (Sea Level Anomalies, Mean Dynamic Topography and Sea Surface Temperature) and in-situ (Temperature and Salinity profiles) on a 1/4 degree regular grid have been used to derive the global surface total alkalinity and dissolved inorganic carbon for evaluation purpose. The basin scale difference of TA between Arabian Sea and Bay of Bengal is clearly evident in the processed satellite data. On an average the northern

Arabian Sea is having the highest TA compare to similar latitudes in Bay of Bengal. TA over the Bay of Bengal ranged between 1600 to 2600 $\mu\text{mol kg}^{-1}$. The lower values of Bay of Bengal is attributed to high riverine inputs which in general is low in TA however high surface TA in the Arabian Sea is presumably linked to Persian Gulf water which comes in from the north west boundary and spreads all over the basin. Here the TA ranged from 1800 to 2600 $\mu\text{mol kg}^{-1}$ on annual basis. The DIC values also mimic the TA distribution which is a normal phenomenon in ocean. Interestingly the lowest TA and DIC values in the Bay of Bengal are associated with the summer monsoon. This presumably reflects the empirical nature of the relationship where salinity plays a critical role especially with respect to the TA.

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- I. **Table 1** gives the accuracy estimate for the T/S near real time fields.

1.0 Introduction

Accumulation of anthropogenic CO₂ in the atmosphere is a major environmental concern because of its effect on future climate scenario. Almost half of the anthropogenic CO₂ emitted presently is being taken up by the oceans. Several studies have suggested the net global ocean CO₂ uptake is around 1.5 to 2.0 Pg -Cy⁻¹ (Pg = Peta grams = 10¹⁵g = 1 Giga ton) (Takahashi et al., 2009) raising concerns about ocean acidification (decrease in ocean pH) as CO₂ highly soluble and interacts with surface ocean (see review by Mostofa et al., 2015). From chemical perspective one of the most important factors which influence the marine carbon cycle is the carbonate chemistry as it controls the pH of the sea water and also acts as a primary buffer in the ocean (Goodwin et al., 2008). The carbonate system of the oceans plays a key role in controlling the pressure of carbon dioxide in the atmosphere which helps to regulate the temperature of earth. It also act as a sink of dissolve inorganic carbon therefore regulating a long term global carbon balance however the export of calcium carbonate (CaCO₃) from the surface ocean remains poorly understood. Dissolved compounds that make up the carbonate system in water are aqueous carbon dioxide (aqCO₂), bicarbonate (HCO₃⁻) and carbonate ion (CO₃²⁻). Measurements of any two of the seawater carbonate system variables (i.e., dissolved inorganic carbon, alkalinity, pH or partial pressure of carbon dioxide) in combinations with observations of temperature, salinity, silicate and phosphate concentrations are adequate to determine the complex CO₂ system. The measurement of alkalinity is particularly useful because of its conservative nature with respect to water mixing. Change in alkalinity is also independent of temperature, pressure unlike pCO₂, pH and concentrations of individual chemical species (Wolf-Gladrow et al., 2007). The total concentration, C_T for inorganic carbon in seawater is called the dissolved inorganic carbon (DIC) or total CO₂ or (ΣCO₂). The DIC of the seawater sample is the sum of the concentrations of the dissolved inorganic carbon species. Since alkalinity (TA) and DIC are conservative therefore both are used in ocean carbon models. Both DIC and TA can be used to estimate the air-sea CO₂ fluxes with inputs of some more ancillary parameters. Total alkalinity and DIC have unique empirical relations with surface temperature, salinity and chlorophyll for different oceanic basins raising the possibility of satellite based approach. Presently all these parameter now can be obtained/derived from satellite data therefore a synoptic view of large scale changes can be investigated.

1.1 Total Alkalinity (TA) and Dissolved Inorganic Carbon (DIC)

Alkalinity of a solution is the capacity for solutes it contains to react with and neutralize acid. Chemically, alkalinity in a mixed electrolyte solution is the excess in bases (proton acceptors) over acids (proton donors) in the solution. Earlier alkalinity has been clearly defined by (Dickson, 1981). The property of alkalinity must be determined by titration with a strong acid (often hydrochloric acid), and the end point of the titration is the pH at which virtually all solutes contributing to alkalinity have reacted (reached a pH of 4.5). The end-point pH that has been used in the titration is a function of the kinds of solute species responsible for the alkalinity and their concentrations. In almost all natural waters alkalinity is produced by dissolved carbon dioxide species, bicarbonates and carbonates and the end point mentioned above are selected keeping this on mind however underunusual circumstances non-carbonate alkalinity may also be important. Some of the important contributors to non-carbonate alkalinity include hydroxide, silicate, borate, and organic ligands, especially acetate and propionate and all together is referred as Total Alkalinity(TA). Under normal oceanic conditions carbonate alkalinity is important which comprised of 96% of the TA and rest contribute 4%. Total alkalinity is useful and important in context to carbonate system in seawater. The TA of oxic sea water is represented by equation (1.0).

$$\text{Total alkalinity} = \text{T.A.} = [\text{HCO}_3^-] + 2 [\text{CO}_3^{2-}] + [\text{B(OH)}_4^-] + [\text{HPO}_4^{2-}] + 2 [\text{PO}_4^{3-}] + \text{-----}(1.0) \\ [\text{H}_3\text{SiO}_4^-] + 2 [\text{H}_2\text{SiO}_4^{2-}] + [\text{NH}_3] - [\text{H}^+] + [\text{OH}^-] + \\ [\text{other conjugate bases of weak acids}]$$

The section of the TA which is attributed to the presence of carbonates and bicarbonates is termed as carbonate alkalinity and shown in equation (1.1)

$$\text{Carbonate alkalinity} = \text{C.A.} = 2 [\text{CO}_3^{2-}] + [\text{HCO}_3^-] \text{-----} (1.1)$$

where each mole of carbonate ion contributes units of titratable charge. The reported units of TA are moles of charge per kilogram or per litre of sea water can also be referred to as equivalent of charge (meq). The alkalinity of seawater is much large than that of freshwater and so is the DIC. The sea surface distribution of alkalinity is affected by various biogeochemical processes which include 1) changes in seawater dilution due to evaporation and precipitation 2) Riverine inputs of low fresh water alkalinity 3) Production and export of calcium carbonate (CaCO₃) 4) Consumption and regeneration

of nutrients due to primary production and mineralization of dissolved organic or inorganic compounds 5) Deep water ventilation or upwelling of subsurface water with high alkalinity formed due to the dissolution of calcium carbonates (CaCO_3) (Wolf-Gladrow et al., 2007; Lee et al., 2006; Cai et al., 2010; Friis et al., 2003; Millero et al., 1998b; Armstrong et al., 2001). Solubility of the different dissolved inorganic carbon species as a function of pH is shown in Figure 1 (After Zeebe, R.E. and D. Wolf-Gladrow (2001) Elsevier Oceanography Series, 65, Elsevier, p. 10). On the time scale of 1000 years or less oceanic carbonate system is modified primarily due to biological process. Concentrations generally increase with water depth due to calcium carbonate dissolution and degradation of organic matter.

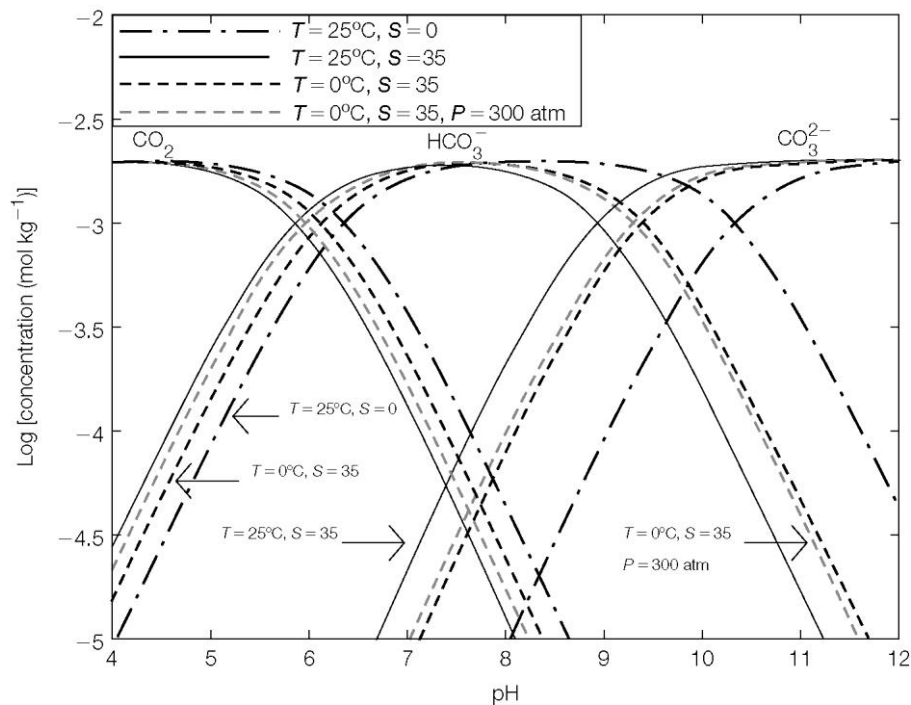


Figure 1: Effect of temperature, pressure, and salinity on speciation of the dissolved inorganic carbon for $\Sigma\text{CO}_2 = 2 \text{ mmol/kg}$. *Source:* After Zeebe, R.E. and D. Wolf-Gladrow (2001) Elsevier Oceanography Series, 65, Elsevier, p. 10.

In water the inorganic carbon exist in four different forms the first one being aqueous carbon dioxide $\text{CO}_2(\text{aq})$ and three being the product of hydration. These are carbonic acid, bicarbonate and carbonate. The total concentrations together are called the dissolve inorganic carbon or (DIC) or total CO_2 (ΣCO_2) as earlier mentioned. Sea water almost has equal amount of DIC and TA because the main source of these is riverine bicarbonate ion which makes equal contribution to both constituents. Some of the removal process include calcium carbonate precipitation, hydrothermal circulation and reverse weathering

in the sediments (Emerson and Hedges, 2008). The chemical characters of the particulate material that degrades and dissolved determine the ratio of TA and DIC. Organic matter degradation and oxidation produce CO_2 which gets dissolved in water. This increases the DIC but does not change the alkalinity of the water as it is a measure of charged species. Since there is not charge associated with CO_2 its release into the solution does not alter the alkalinity. However dissolution of calcium carbonate results in changes in TA and DIC. One mole of calcium carbonate dissolution causes an increase in alkanlity that is twice that of DIC because carbonate introduces two charge equivalents for each mole of carbon change. This makes it clear those changes in alkalinity and DIC in seawater is tightly coupled with the biogeochemical changes that happen within the euphotic zone. Observed Depth profiles of TA and DIC from world oceans have been presented in Figure 2.

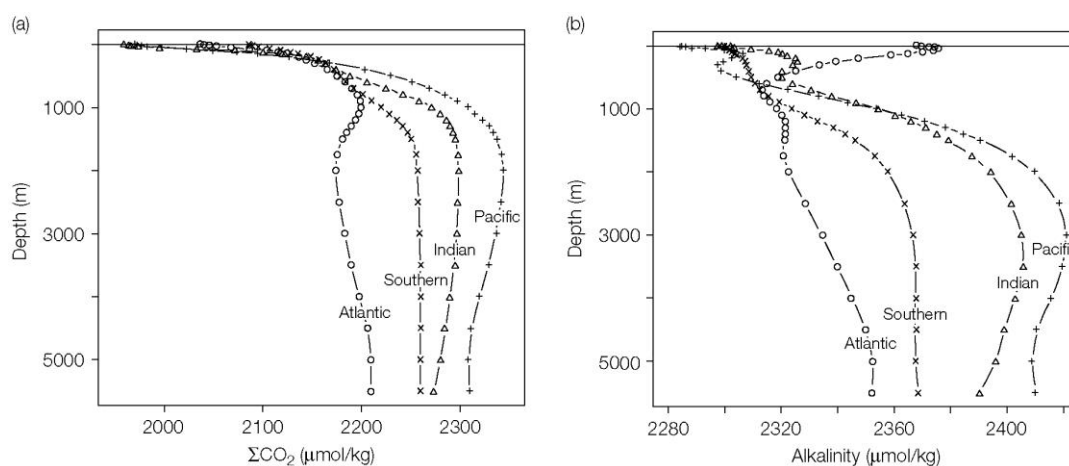


Figure 2: Geographic variations in (a) PCO_2 and (b) total alkalinity as reflected by average vertical profiles for each ocean. The averages were computed from data collected during GEOSECS, TTO, SAVE, and INDIGO expeditions. The global dataset includes results from 12,011. Hydrographic stations sampled during 116 cruises that were conducted between 1972 and 1999. *Source:* After Key, R. M., *et al.* (2004) *Global Biogeochemical Cycles* 18, GB4031, p. 23.

1.2 Satellite based estimation of TA and DIC as an input for estimation of surface $p\text{CO}_2$

Recent advances in satellite oceanography have open up new dimensions for understanding various biogeochemical properties in synoptic scale because of its large spatial coverage. Multiple studies have shown strong relationships between sea surface temperature, salinity and chlorophyll with TA and DIC suggesting the same can be

exploited for observing basin scale changes. These relationships have been effectively used to estimate the surface $p\text{CO}_2$ fluxes in Atlantic, Pacific Ocean and Indian Ocean (Boutin et al., 1999; Lefèvre et al., 2002; Sarma et al., 2003; Sarma et al., 2006). Sarma et al. 2003 showed excellent linear relationship between sea surface salinity and TA from central Arabian Sea and used it to understand basin scale seasonal distribution of surface $p\text{CO}_2$ in conjunction with surface DIC. Such empirical relations have become an excellent tool to understand changes in TA and DIC and in estimation of the Air-Sea CO_2 fluxes. Since satellite derived temperature, salinity and chlorophyll is readily available, it can be used to generate surface maps of these parameters on long term scale to understand larger scale processes. A relationship between climatological salinity and measured TA from north Pacific after (Sarma et al 2003) is shown in Figure 3.

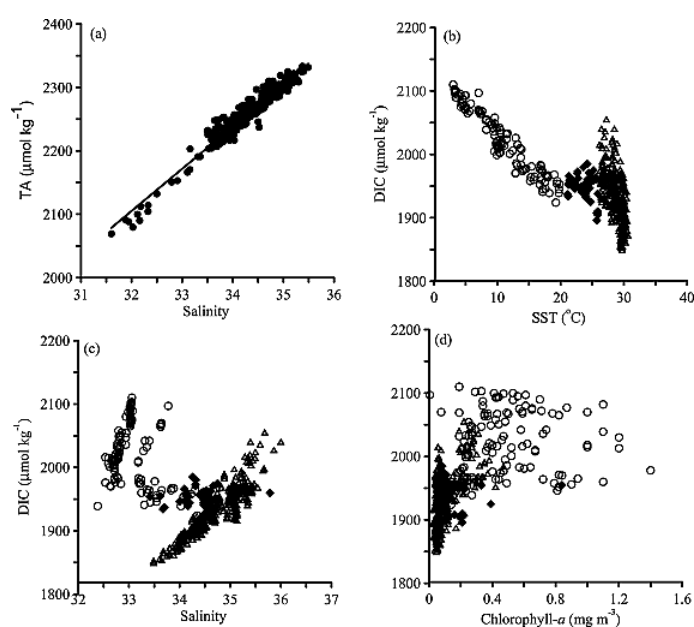


Figure 3: TA versus sea surface salinity and the relations for DIC with (b) sea surface temperature, (c) salinity, and (d) chlorophyll *a* in the North Pacific using NOPACCS data. Shown are SST < 20°C (open circles), >20°C SST < 27.5°C (solid diamonds), and SST > 27.5°C (open triangles). Citation: Sarma et al., (2003).

2.0 Material and Methods

2.1 General relationships between total alkalinity and salinity in ocean:

Several basin scale empirical relations and other approaches such as neural network have been developed for understanding the spatio-temporal distribution of carbon parameters with the help of satellite and in situ data (Friedrich, T., & Oschlies, A. 2009; Ono et al.,

2004; Sarma et al., 2003; Sarma et al., 2006). Satellite based studies are useful to understand basin scale trends due to its large spatial coverage however its accuracy is largely depends on in situ validation and quality of the satellite data. In general, these approaches involve generation of multiple regression equation with sea surface temperature (SST), sea surface salinity (SSS) and chlorophyll to compute mixed layer dissolve inorganic carbon and total alkalinity. Largely, total alkalinity (TA) shows a linear relationship with sea surface salinity in ocean.

2.2 Empirical relations for satellite derived TA and DIC in northern Indian Ocean:

For better retrieval of carbon parameters seasonal multiparameter fit has also been generated (Sarma, 2003) for northern Indian Ocean. Multiple regression equations for different seasons using the mixed layer temperature, salinity and chlorophyll adapted from Sarma (2003) for this product is presented below. The resultant regression fits are:
NE monsoon

NE monsoon

$$\text{DIC} = 845.74 - 20.88 \text{ T} + 47.79 \text{ S} - 34.37 \text{ Chl} [\pm 5 \mu\text{mol kg}^{-1}] \quad (1)$$

$$\text{DIC} = 1071.58 - 17.471 \text{ T} + 39.23 \text{ S} - 31.478 \text{ Chl} [\pm 6.5 \mu\text{mol kg}^{-1}] \quad (2)$$

SW monsoon

$$\text{DIC} = 1454.4 - 23.1 \text{ T} + 33.37 \text{ S} - 23.82 \text{ Chl} [\pm 6 \mu\text{mol kg}^{-1}] \quad (3)$$

Fall monsoon

$$\text{DIC} = 865.5 - 7.6 \text{ T} + 37.8 \text{ S} - 37.9 \text{ Chl} [\pm 8 \mu\text{mol kg}^{-1}] \quad (4)$$

Satellite derived total alkalinity was obtained based on following equation:

$$\text{TA} = 350.8 + 55.6 \text{ S} (\pm 5.7 \mu\text{mol kg}^{-1}) \quad (5)$$

The seasonal equation developed by Sarma (2003) for the Arabian Sea basin shows mixed layer DIC to have distinct relationships with respect to temperature, salinity, and chlorophyll with slope and intercepts of these relations, having shown strong seasonal variability. DIC showed negative relation with temperature, in general, but with seasonal changes in slopes. On the contrary, salinity showed positive relation with DIC in all the

seasons except during SW monsoon which are further detailed in Sarma (2003). Chlorophyll exhibited weak positive relation with DIC in all the seasons except fall monsoon. The relationship between TA and salinity has been determined by using the geometric mean of the data from U.S. JGOFS cruises in the Arabian Sea and the data from the WOCE cruises II across the Arabian Sea and the Bay of Bengal (Goyet et al., 1999) further detailed in Sarma, 2003. This equation is valid for the salinity range of 31 to 36.8. The surface TA maxima and minima coincide with salinity maxima and minima (Goyet et al., 1999).

Once TA and DIC are obtained, programme such as CO₂SYS can be used to compute the air–sea CO₂ fluxes (Lewis and Wallace, 1998). For generation of global surface DIC and TA maps, empirical relations from Sarma, (2003) have been adapted here. These relations have been developed for Arabian Sea and extensively validated. The published multiparameter fit between SSS, SST and chlorophyll *a* was used to generate surface maps of dissolve inorganic carbon and total alkalinity. For this we have used combined satellite data (Sea Level Anomalies, Mean Dynamic Topography and Sea Surface Temperature) and in-situ (Temperature and Salinity profiles) on a 1/4 degree regular grid supplied by <http://marine.copernicus.eu/> also known as Armor-3D L4 Analysis product for developing weekly to monthly level TA and DIC.

This product is a Global Ocean Observation based Product (GOOP) that uses Sea Surface Temperature (SST), Sea Level Anomalies (SLA), Mean Dynamic Topography (MDT) and Temperature (T) and Salinity (S) in-situ vertical profiles. The quality of the 3D T/S and current fields at 1000 m depth is assessed based on comparison with situ data.

Temperature: The SST used as an input of the product helps to have good results for the temperature at the surface. The largest errors are found in the mixed layer depth (0.45 °C). Then, the errors decrease with depth.

Salinity: The largest errors are found near the surface and in the mixed layer depth (<0.070 PSU). Then, like temperature field, errors decrease with depth.

3D T/S fields from GLOBAL_ANALYSIS_PHYS_001_020 are assessed from in-situ data. **Table 1** gives the accuracy estimate for the T/S near real time fields (Further detailed in <http://cmems-resources.cls.fr/documents/QUID/CMEMS-GLO-QUID-001-020.pdf>).

Depth	RMS error temperature (°C)		RMS error salinity (psu)	
	GLOBAL_ANALYSIS_PHYS_001_020	WOA13	GLOBAL_ANALYSIS_PHYS_001_020	WOA13
surface	0.20	1.10	0.057	0.180
100 m	0.40	1.33	0.050	0.150
500 m	0.15	0.65	0.020	0.067
1000 m	0.08	0.33	0.012	0.034
1500 m	0.07	0.17	0.010	0.023

Note for generation of this product surface TS values have been taken as an input. Further product information and quality of the input parameter for TA and DIC is detailed here <http://marine.copernicus.eu/documents/PUM/CMEMS-GLO-PUM-001-020.pdf>. The spatial resolution of the product is 1/4 degree with weekly temporal resolution and detailed further in (Guinehut et al., 2004; Guinehut et al., 2012).

Five sources of input data are used to generate the Armor-3D L4 Analysis product which is given below.

- The temperature and salinity fields of the 2005-2012 WOA13 1/4° climatology computed at NOAA (<https://www.nodc.noaa.gov/OC5/woa13/>);
- In-situ T and S profiles are from the CMEMS INSITU TAC including Argo profiling floats, XBT, CTD and moorings measurements;
- Altimeter sea level anomalies (SLA) are from the CMEMS Sea Level TAC and are weekly combined maps of all processed altimeters with a 1/4° horizontal resolution;
- The Mean Dynamic Topography CNES-CLS13 (Rio et al., 2014) is also used with SLA to compute surface geostrophic current fields in step 3 (see II.3);
- SST data are from daily Reynolds analyses with a 1/4° horizontal resolution, combining AVHRR and in-situ observations (no more AMSR since October

2011) and distributed by the National Climatic Data Center at NOAA

(<http://www.ncdc.noaa.gov/oa/climate/research/sst/oi-daily.php>).

These SST and SSS product generated thereafter are used to derive the TA and DIC.

3.0 Results and Constraints

The robust multiple parameter empirical fit used by Sarma (2003) have been validated for Arabian Sea (Figure 4). These regression equations developed are based on Levitus surface temperature and salinity climatology. In this product we have replaced them with satellite derived sea surface temperature and assimilated salinity as inputs with chlorophyll a from MODIS Aqua at 4 KM resolution. We presume this may lead to modest bias in the outcome of TA and DIC due to inherent errors associated with the satellite data leading to difference in actual magnitude of the data and not the seasonal trends. Further the empirical relations used here are generated for the northern Indian Ocean and therefore fine tuning of the same with insitu measurements for all other oceanic basins is a good option. Measurements carried out in Arabian Sea and Bay of Bengal and insitu data available for the same period (December 2013 to June 2016) is being analyzed and processed for understanding the bias associated with the absolute values between satellite derived and insitu measurements. Therefore any significant changes observed may lead to further reprocessing and fine tuning of the data products. Furthermore, the interrelationships around coastal waters may be more complex for which development of regional specific algorithms currently being actively considered. The users are encouraged to validate and modify the empirical relations for local scale. The monthly variation of satellite derived surface TA and DIC are being illustrated in Figures 5 to 17. The basin scale difference of TA between Arabian Sea and Bay of Bengal is clearly evident in the processed satellite data. On an average the northern Arabian Sea is having the highest TA compare to similar latitudes in Bay of Bengal. TA over the Bay of Bengal ranged between 1600 to 2600 $\mu\text{mol kg}^{-1}$. The lower values of Bay of Bengal is attributed to high riverine inputs which in general is low in TA however high surface TA in the Arabian Sea is presumably linked to Persian Gulf water which comes in from the north west boundary and spreads all over the basin. Here the TA ranged from 1800 to 2600 $\mu\text{mol kg}^{-1}$ on annual basis.

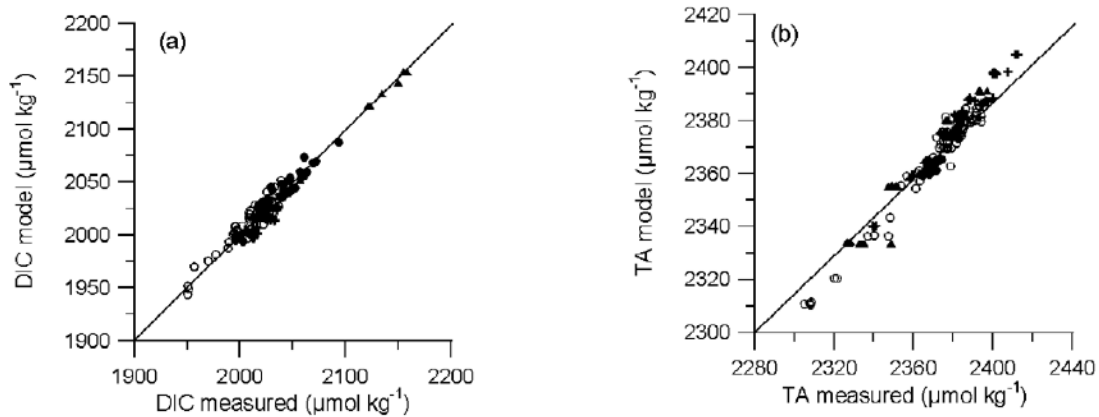


Figure 4: Modeled DIC based on multi parameter fit versus analytically measured DIC from Arabian Sea (b) Modeled TA based on multi parameter fit versus analytically measured DIC from Arabian Sea after Sarma et al., (2003).

The DIC values also mimic the TA distribution which is a normal phenomenon in ocean. Interestingly the lowest TA and DIC values in the Bay of Bengal are associated with the summer monsoon. This presumably reflects the empirical nature of the relationship where salinity plays a critical role especially with respect to the TA. More insitu measurements in tandem with various hydrographic parameters in the northern Indian Ocean should improve this.

Jan-2014

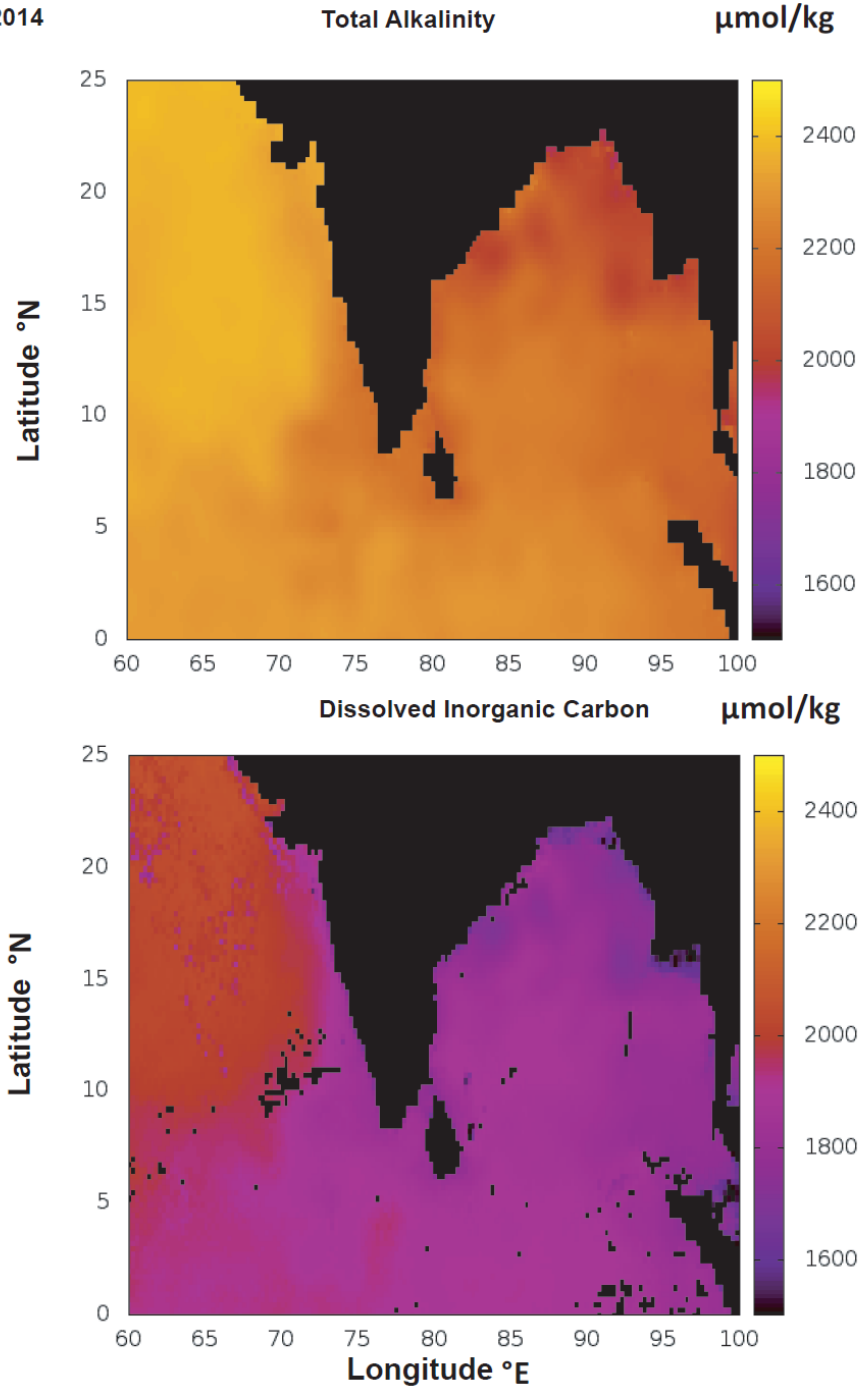


Figure 5: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of January-2014 with $\frac{1}{4}$ degree grid.

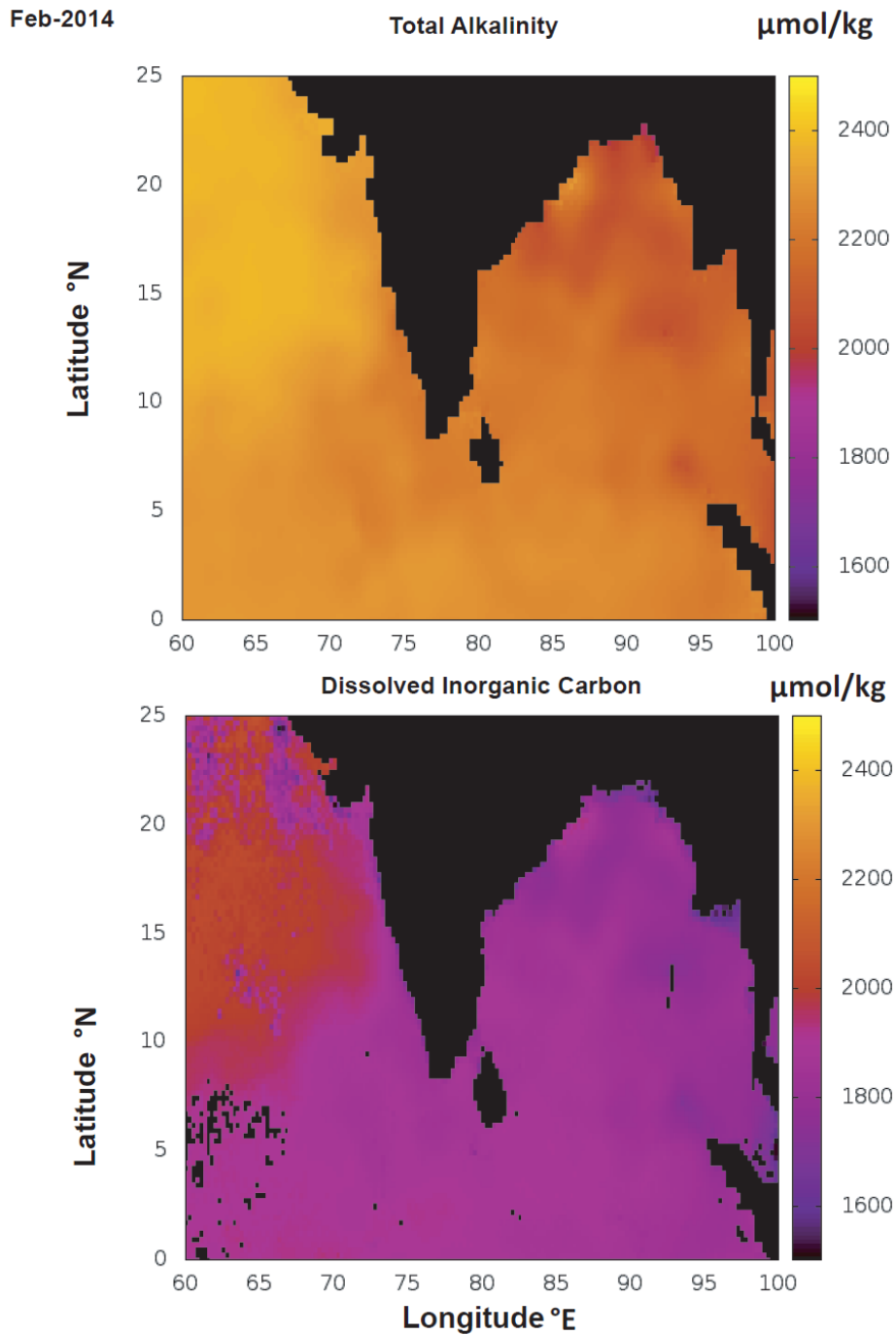


Figure 6: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of February-2014 with $\frac{1}{4}$ degree grid.

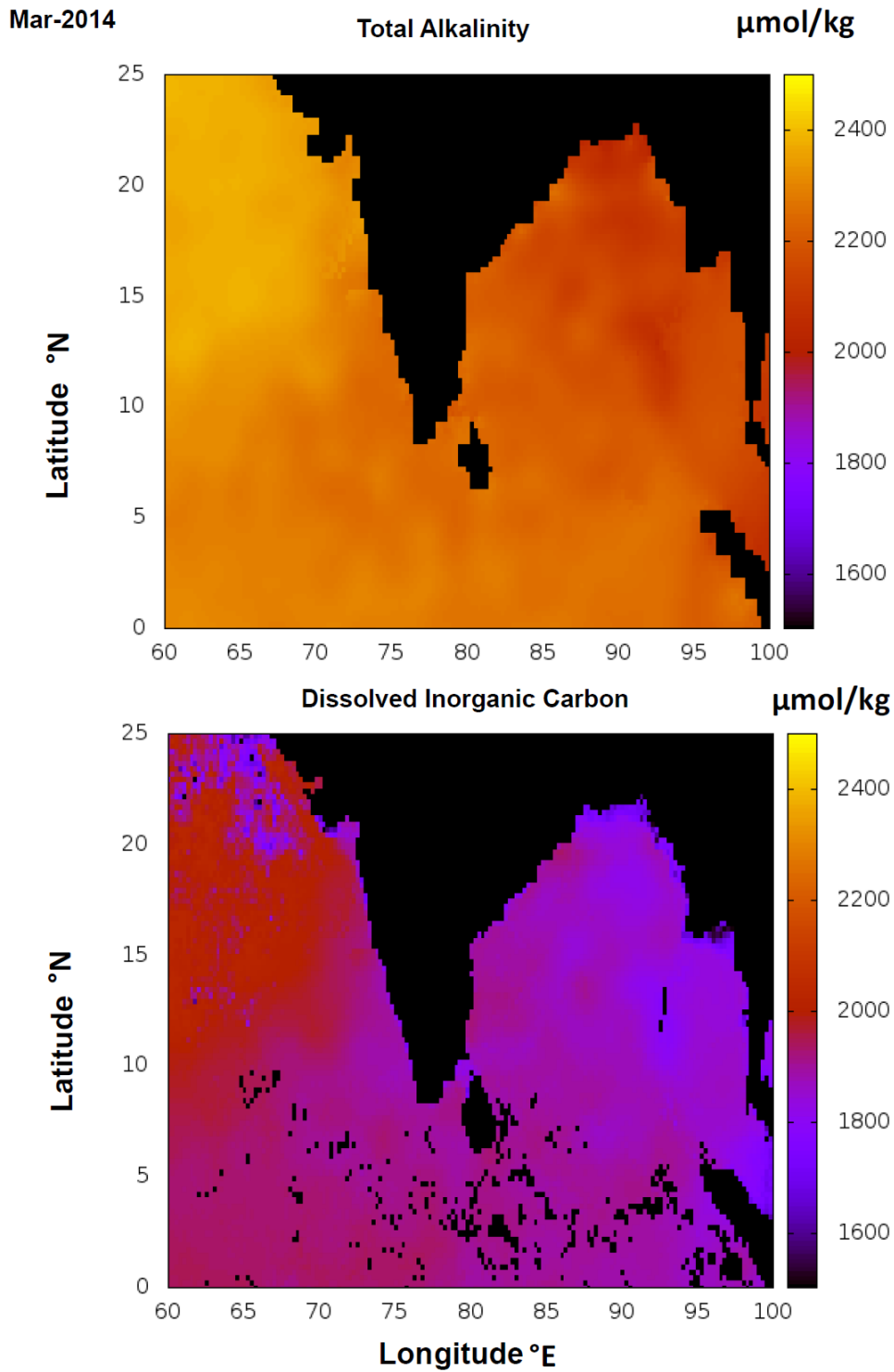


Figure 7: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of March-2014 with $\frac{1}{4}$ degree grid.

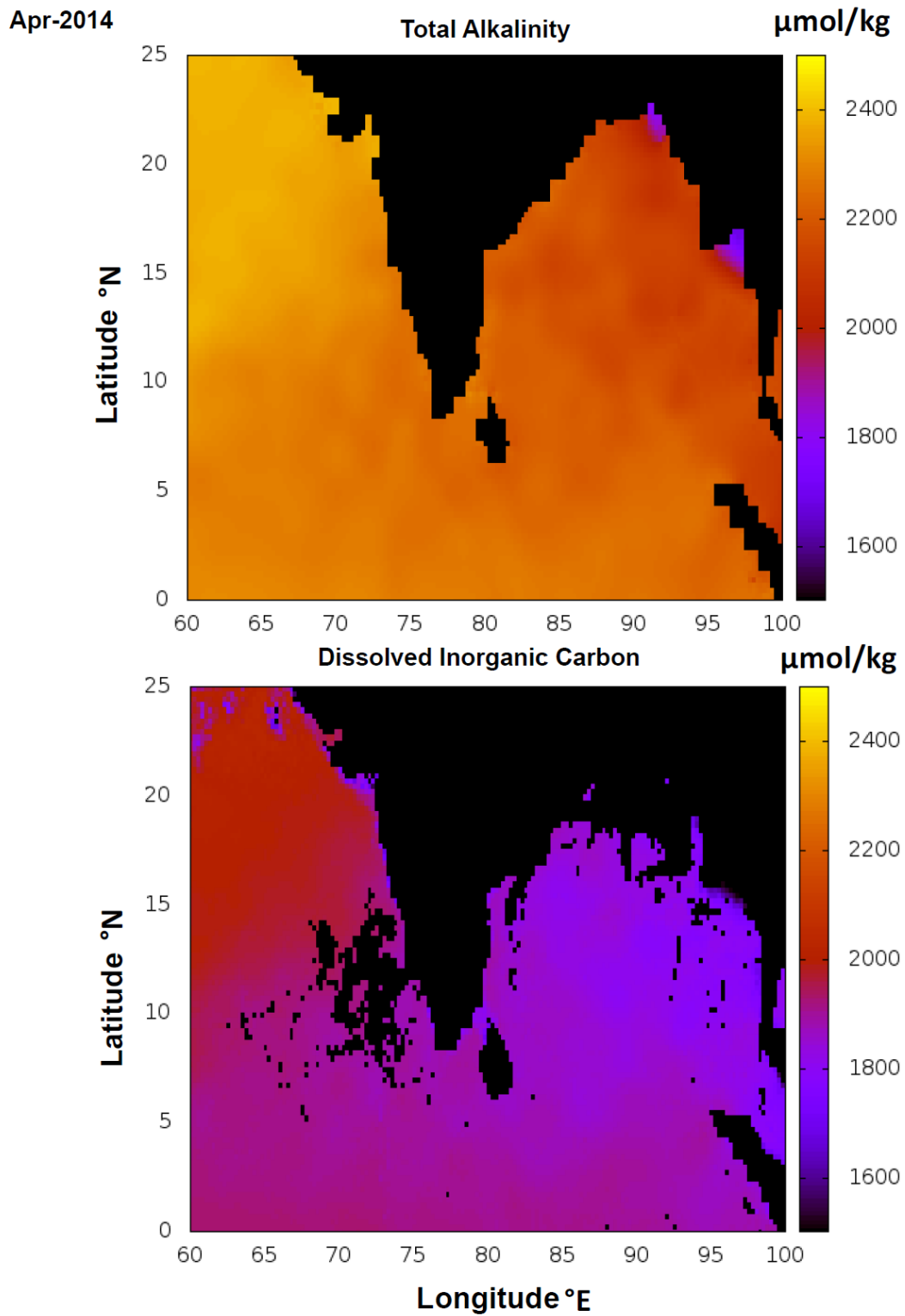


Figure 8: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of April-2014 with $\frac{1}{4}$ degree grid.

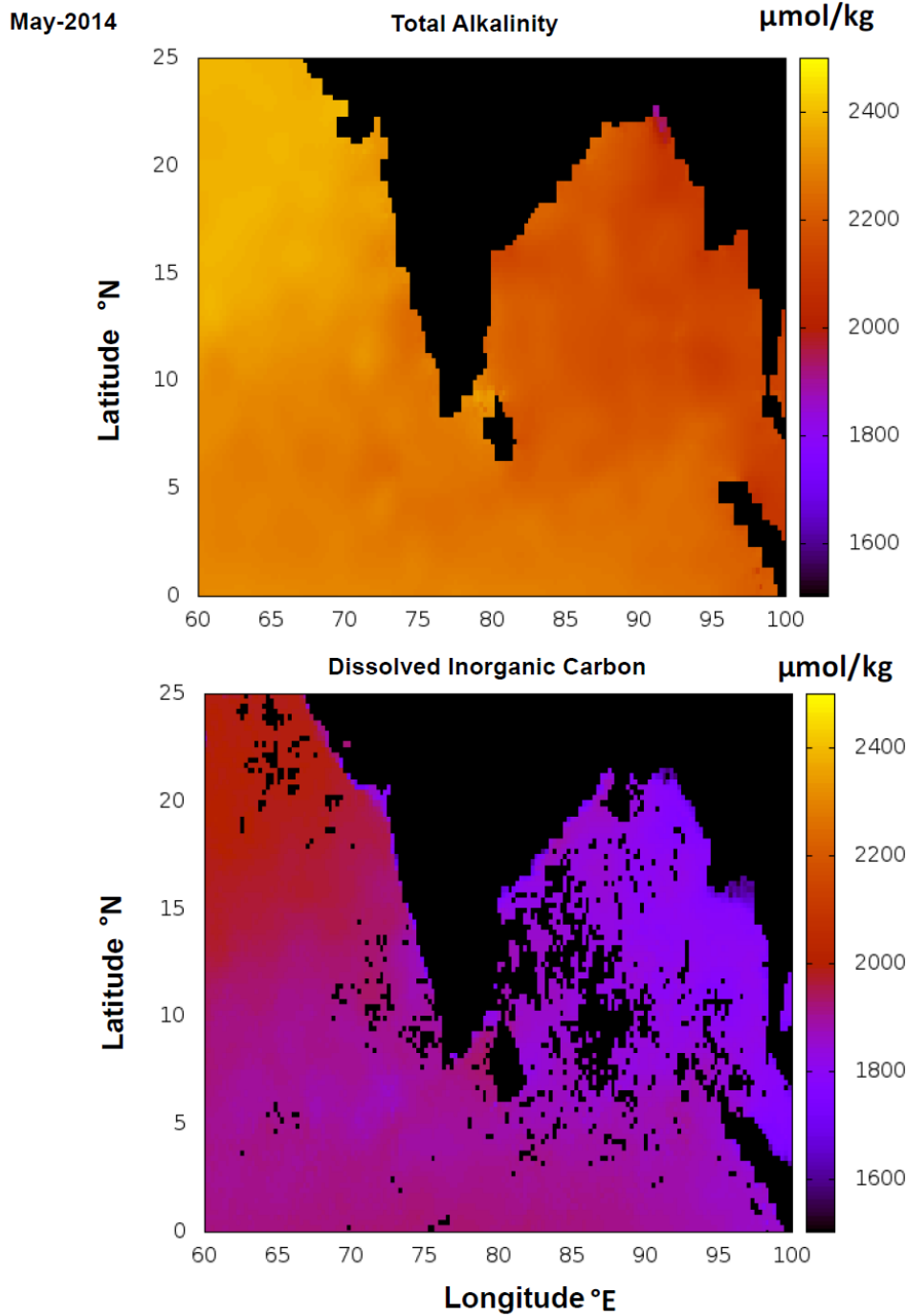


Figure 9: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of May-2014 with $\frac{1}{4}$ degree grid.

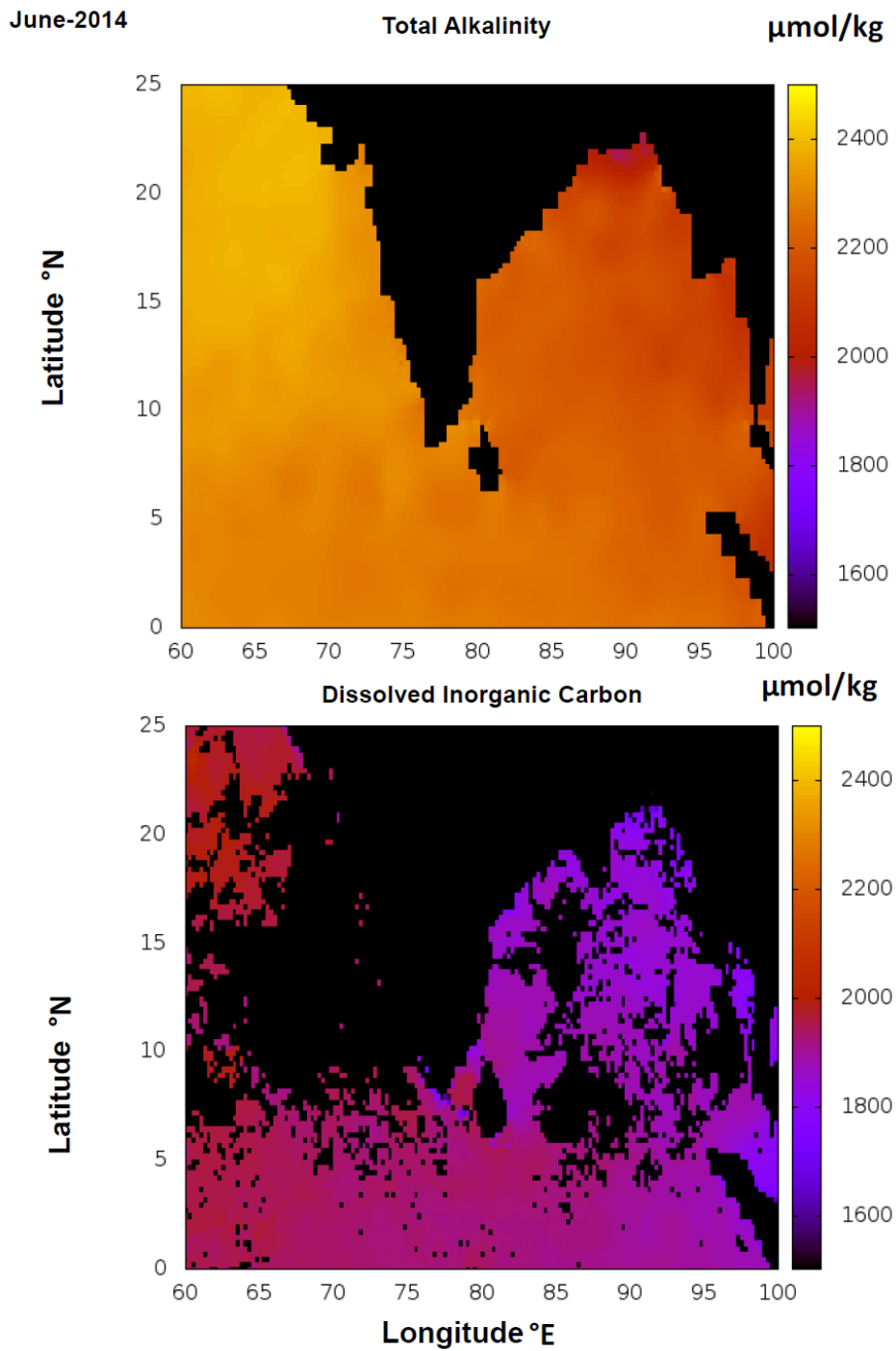


Figure 10: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of June-2014 with $\frac{1}{4}$ degree grid.

July-2014

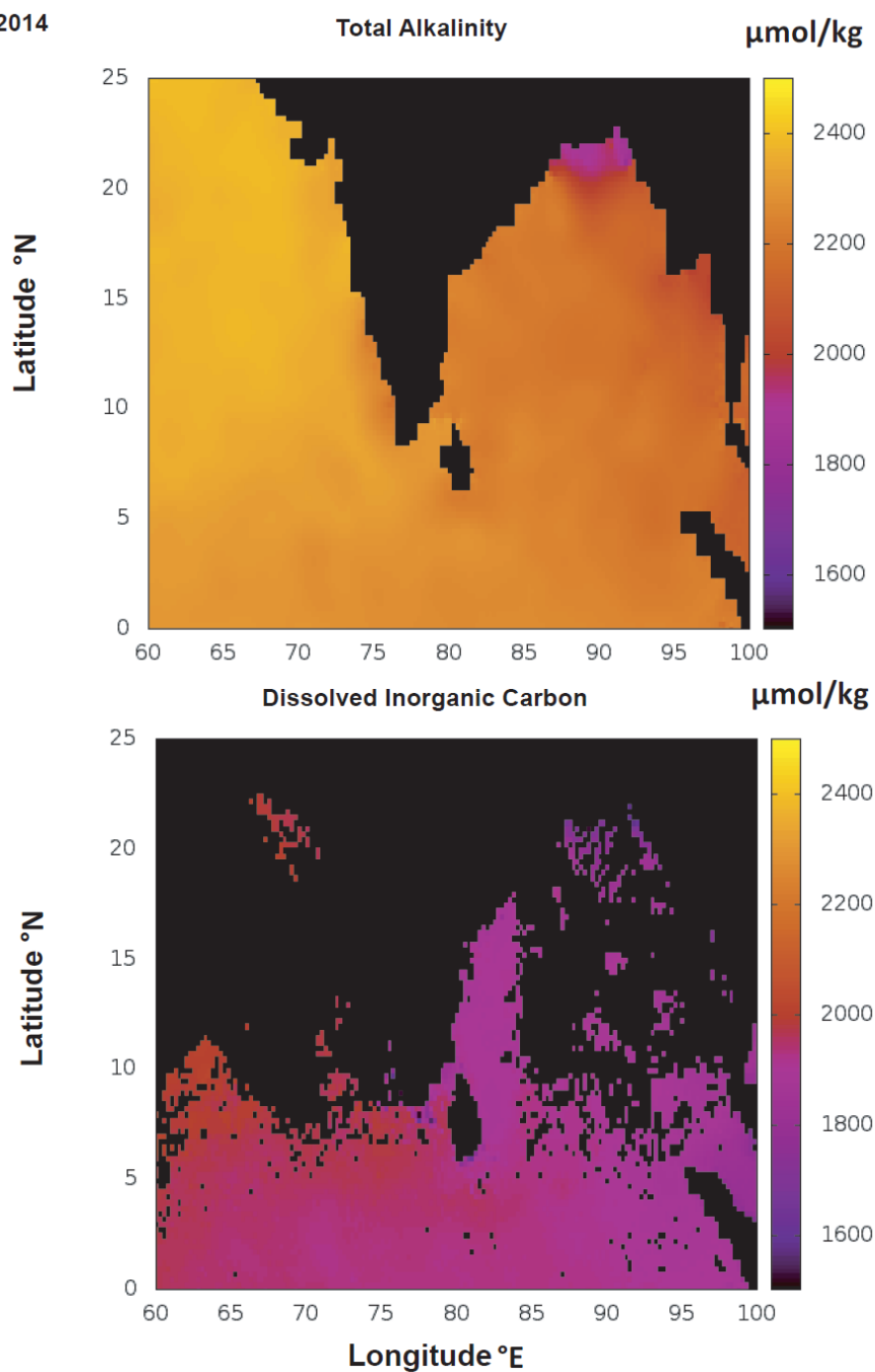


Figure 11: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of July-2014 with $\frac{1}{4}$ degree grid.

Aug-2014

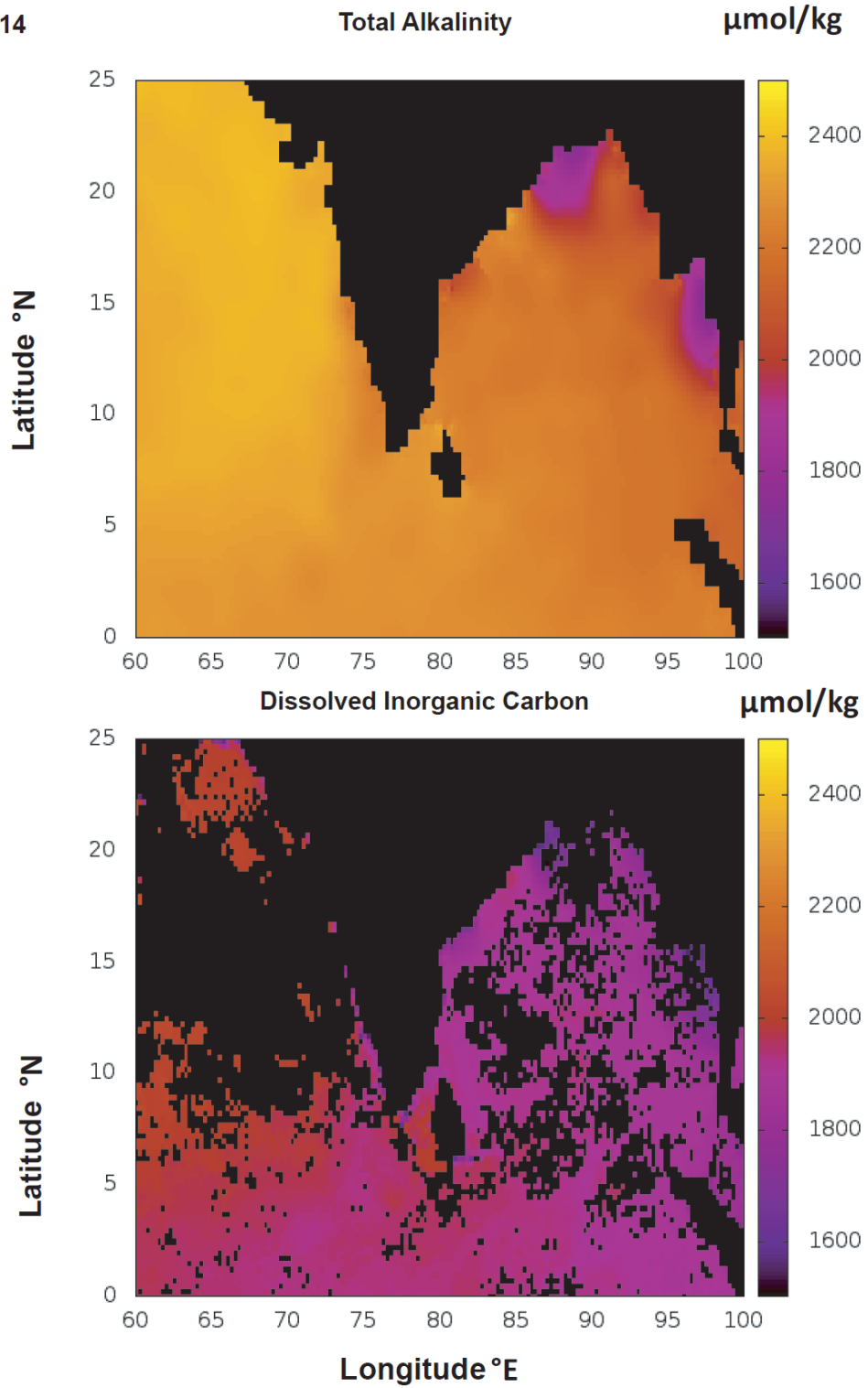


Figure 12: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of August-2014 with $\frac{1}{4}$ degree grid.

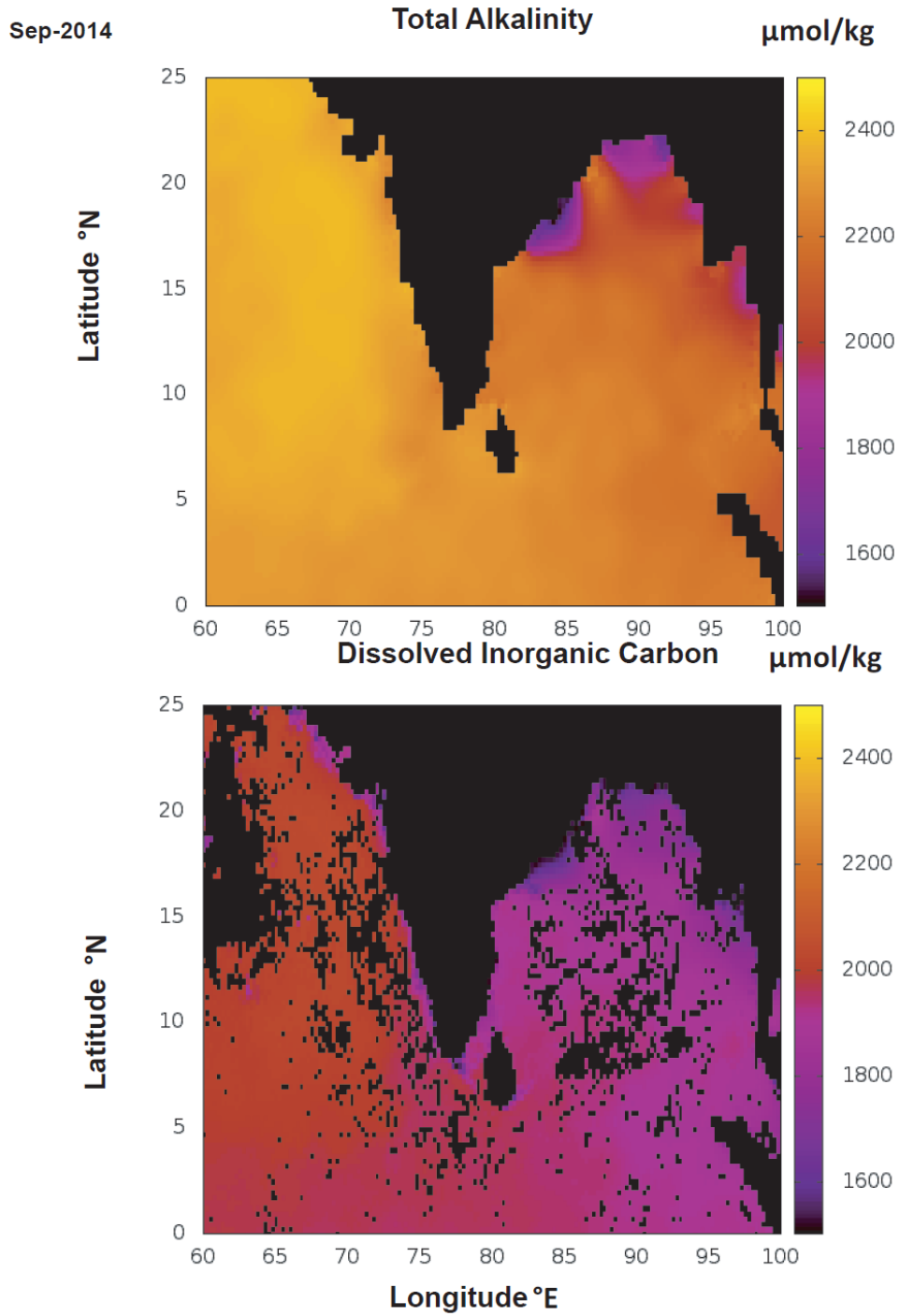


Figure 13: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of September-2014 with $\frac{1}{4}$ degree grid.

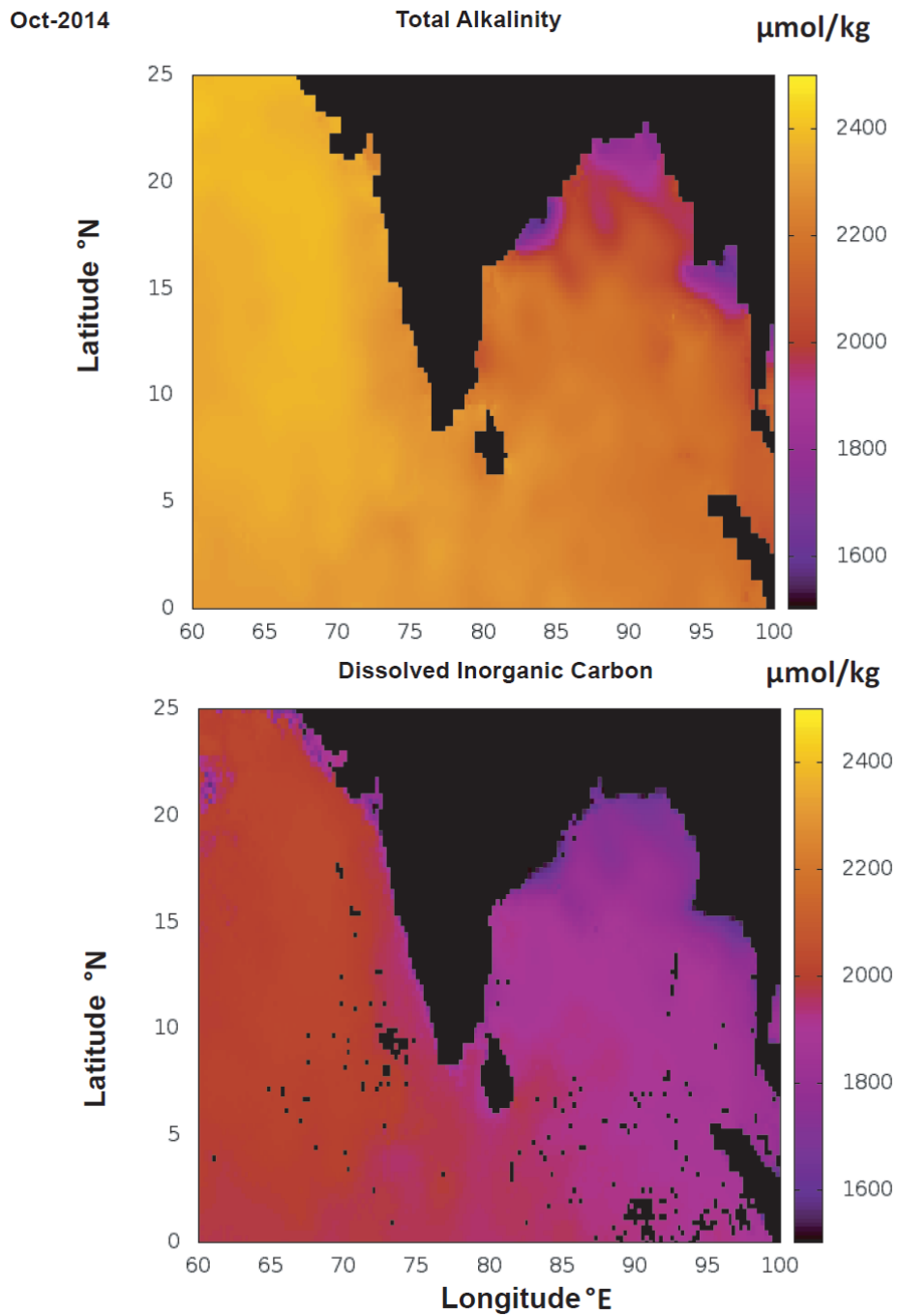


Figure 14: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of October-2014 with $\frac{1}{4}$ degree grid.

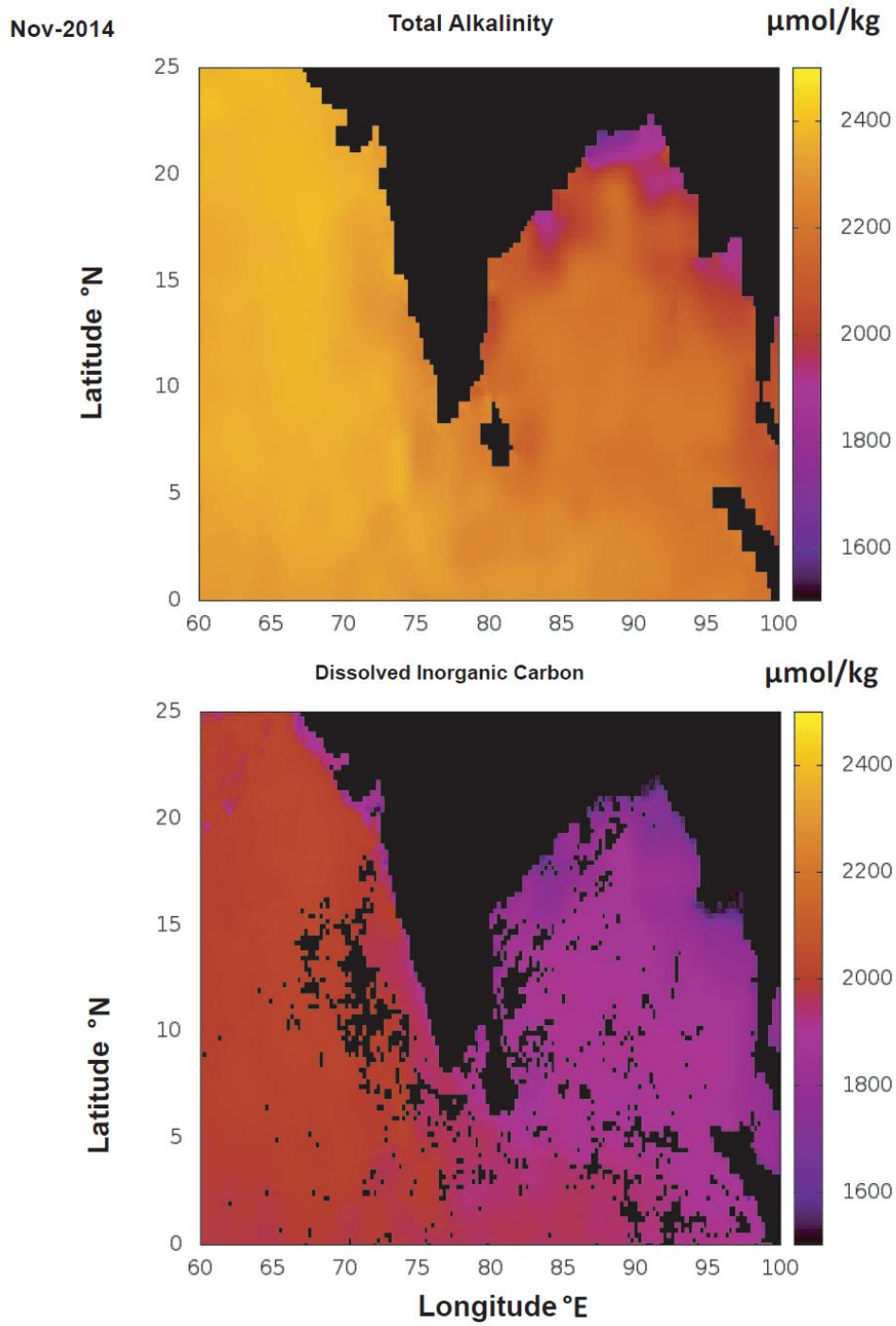


Figure 15: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of November-2014 with $\frac{1}{4}$ degree grid.

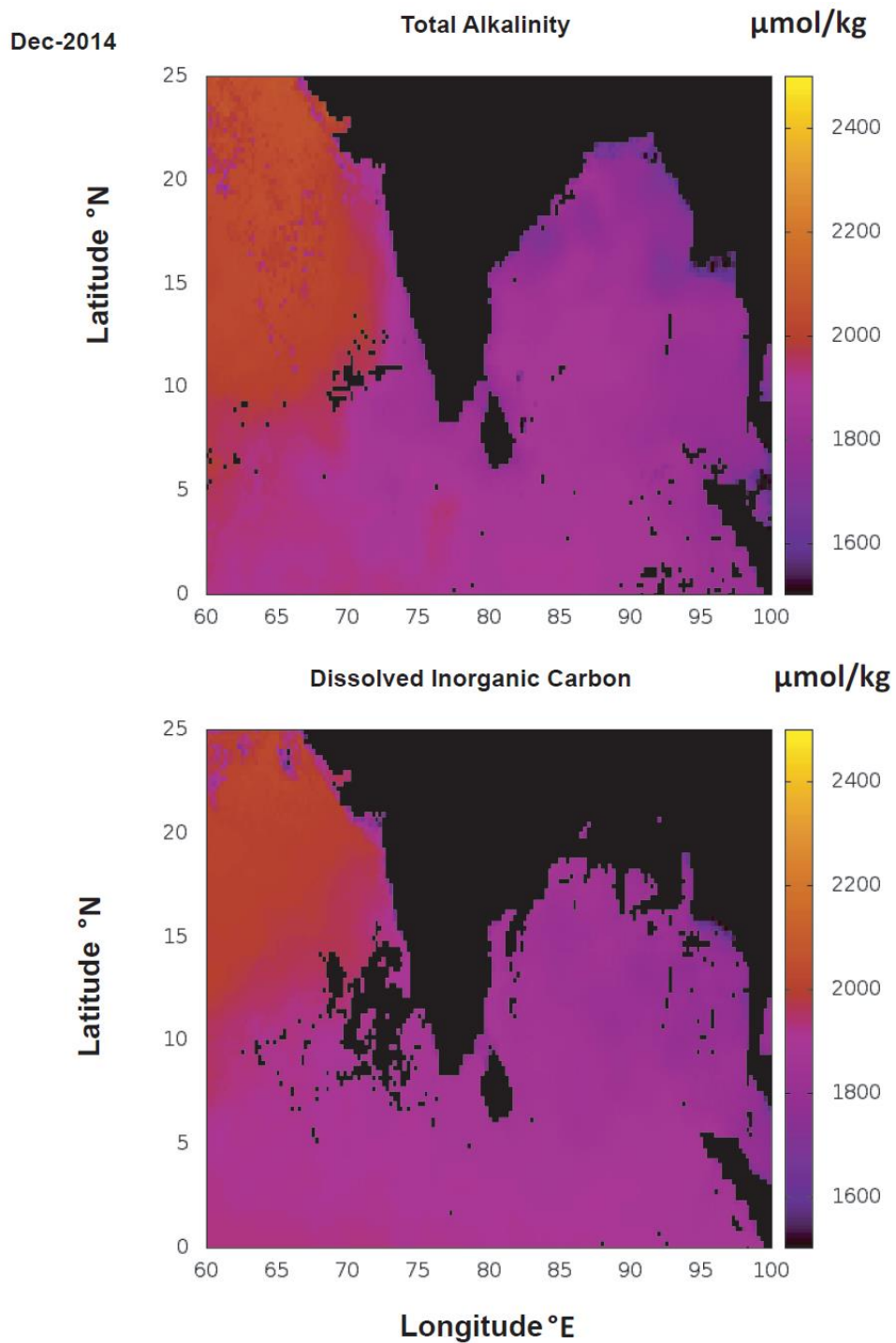


Figure 16: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of December-2014 with $\frac{1}{4}$ degree grid.

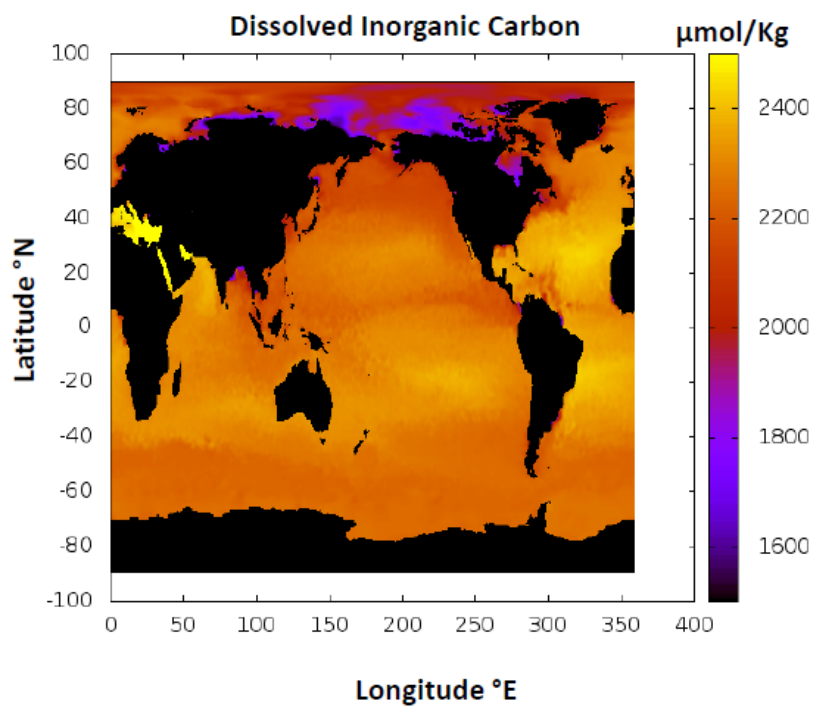
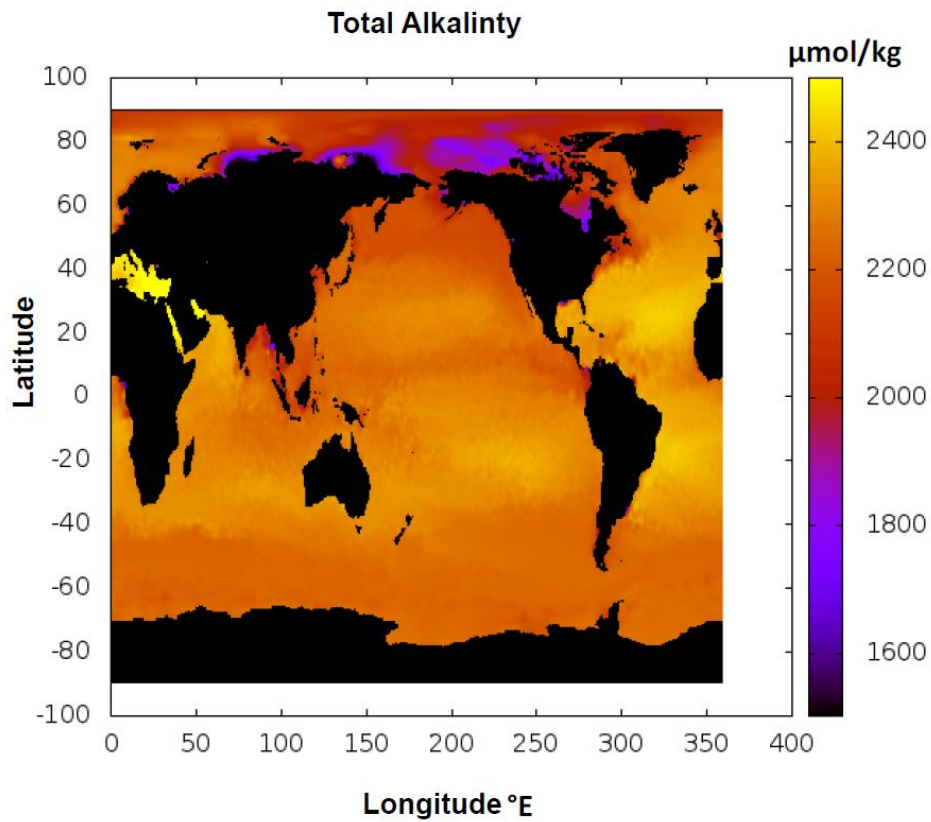


Figure 17: Satellite derived surface profiles of total alkalinity (TA) and dissolved Inorganic carbon (DIC) from northern Indian Ocean for the month of August-2014 with ¼ degree grid.

4.0 Note:

The user assumes all risk arising from his/her use of data. Data are intended to be research-quality and include estimates of data quality and accuracy, but it is possible that these estimates or the data themselves contain errors. It is the sole responsibility of the user to assess if the data are appropriate for his/her use, and to interpret the data, data quality, and data accuracy accordingly. Authors are also welcome to do the necessary validation and report. This is an research and development product therefore it is likely that further improvement, reprocessing and validation will be carried out specific to northern Indian Ocean and will be updated accordingly with necessary changes made.

5.0 References

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